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Innovative Grant 2010 Report
Spin Torque Nano Oscillator Detector and Antenna Characterization

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UNCLASSIFIED: Dist A. Approved for public release

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
06 JUL 2011	**N/A**	**-**

4. TITLE AND SUBTITLE
Innovative Grant 2010 Report Spin torque Nano Oscillator Detector and Antenna Characterization

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Thomas Meitzler; Elena Bankowski; Thomas Reynolds; Steven Zielinski

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
US Army RDECOM-TARDEC 6501 E 11 Mile Rd Warren, MI 48397-5000, USA

8. PERFORMING ORGANIZATION REPORT NUMBER
21975

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
US Army RDECOM-TARDEC 6501 E 11 Mile Rd Warren, MI 48397-5000, USA

10. SPONSOR/MONITOR'S ACRONYM(S)
TACOM/TARDEC/RDECOM

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
21975

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
The original document contains color images.

14. ABSTRACT

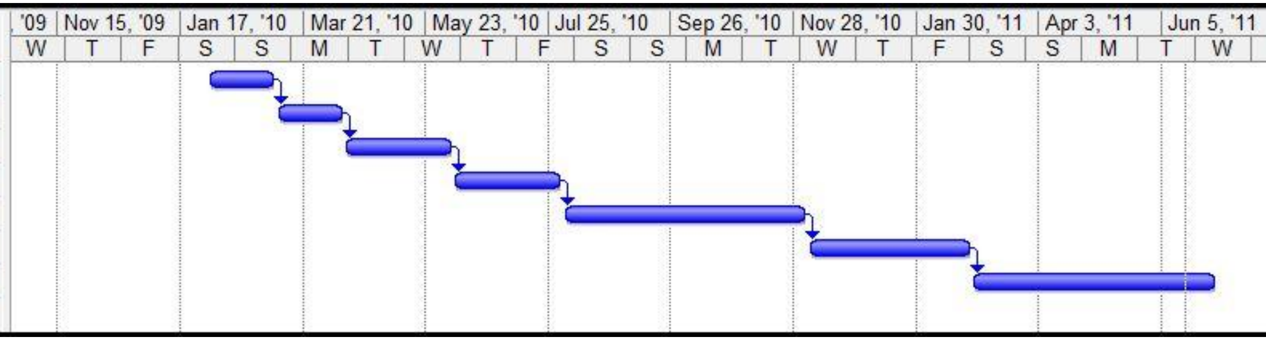
15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**SAR**	**19**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Schedule

	Task Name	Duration
1	Contract package preparat	25 days
2	Development of optimized	25 days
3	Multilayer fabrication	40 days
4	Nano-patterning	40 days
5	Fabrication & testing of ST	90 days
6	Integration into SEA	60 days
7	Testing	90 days



Total Funds
Innovation Grant $100K
CERDEC matching Funds for novel embedded antenna research +50K
Total Cost: ***$150K***

Fabrication of spintronics radar detectors $100K
TARDEC, RDECOM PI Dr. Thomas Meitzler and Co-PI Dr. Elena Bankowski $50K

The full amount of the innovation grant dollars was disbursed .

Accomplishments

- DC characterization of magnetic tunnel junctions (MTJ) completed.
- Circuit design including ESD protection completed.
- Microwave characterization of magnetic tunnel junctions completed.
- Completed putting together all enclosure and electronic components (inductors, ESD protection diodes, SMA flange connectors).
- Ferromagnetic Resonance Frequency (FMR) measurements of the metal junction diodes completed.
- Ten prototype devices fabricated by UC-Irvine and delivered to TARDEC.
- All ten antennas characterized in the Sensor Enhanced Armor lab anechoic chamber for signal gain versus frequency.
- Surrogate armor coupon modified to contain an antenna and MTJ detector.
- Measurements made of the antenna and detector embedded in armor.

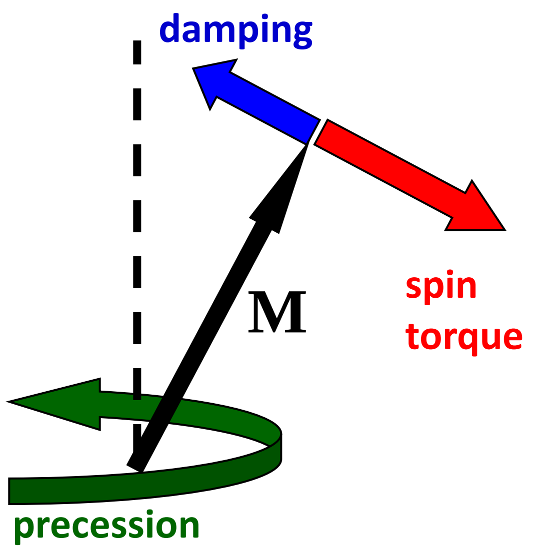
STNO Detector Characterization

- 1 – 6 GHz initial scan to determine approximate resonance frequency
  - A group: focused scans at 4-6 GHz
  - B group: focused scans at 1-3 GHz
- 10 Detectors were tuned for maximum sensitivity from 0 to 3 turns at 1/2 turn increments
- Multiple peaks are present on some detectors
- B group devices typically have a higher voltage output (4B was the highest at approximately 1mV)
- Tuning the magnet on the B group changes both the sensitivity and resonance frequency. For the A group, it only changes the sensitivity

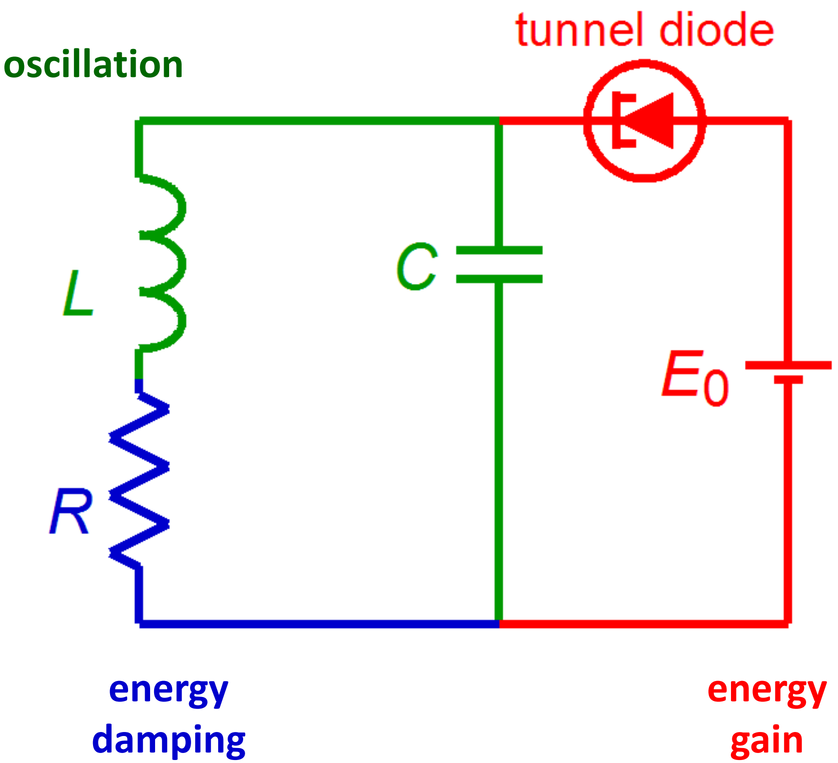
Description of Research

STNO and conventional oscillator

Spin-torque nano-oscillator



Electrical oscillator



Description of Research

Nonlinear oscillator model

oscillation (precession)

positive damping (Gilbert torque)

negative damping (spin-transfer torque)

$$\frac{dc}{dt} + i\omega(p)c + \Gamma_+(p)c - \Gamma_-(p)c = 0$$

C is the complex **amplitude** of oscillations

$p = |c|^2$ is the (dimensionless) oscillation **power**

$\phi = \arg(c)$ is the oscillation **phase**

Description of Research

Stochastic nonlinear oscillator model

Stochastic Langevin equation:

$$\frac{dc}{dt} + i\omega(p)c + \Gamma_{+}(p)c - \Gamma_{-}(p)c = f_{\mathrm{n}}(t)$$

Random thermal noise:

$$\left\langle f_{\mathrm{n}}(t) f_{\mathrm{n}}^{*}(t') \right\rangle = 2D_{\mathrm{n}}\delta(t - t')$$

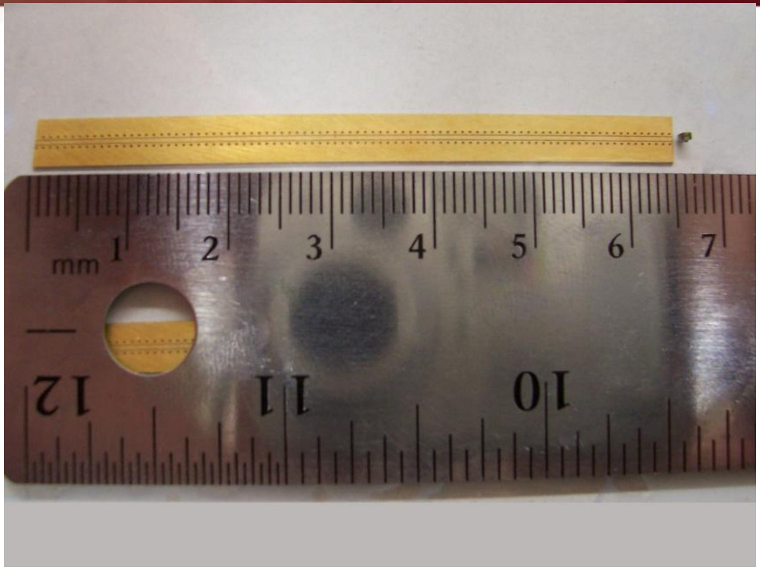
$$D_{\mathrm{n}}(p) = \Gamma_{+}(p)\eta(p) = \Gamma_{+}(p)\frac{k_{\mathrm{B}}T}{\lambda\omega(p)}$$

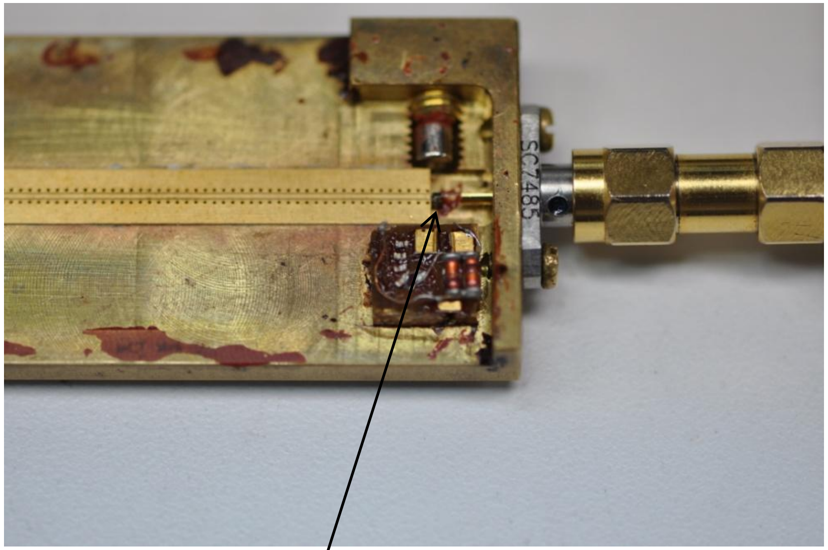
$$\eta = \frac{k_{\mathrm{B}}T}{\lambda\omega(p)}$$ – thermal equilibrium power of oscillations:

$$\left\langle |c|^{2} \right\rangle_{\Gamma_{-}=0} = \left\langle p \right\rangle_{\Gamma_{-}=0} = \eta$$

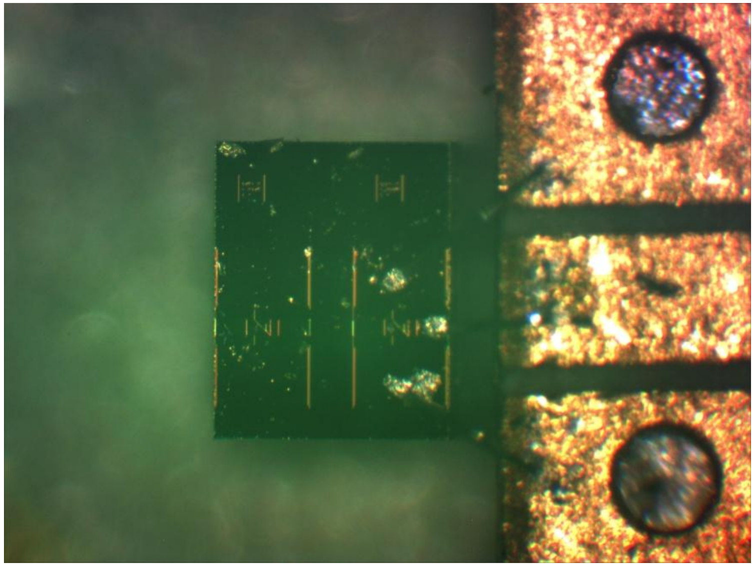
Device Fabrication

Coplanar antenna



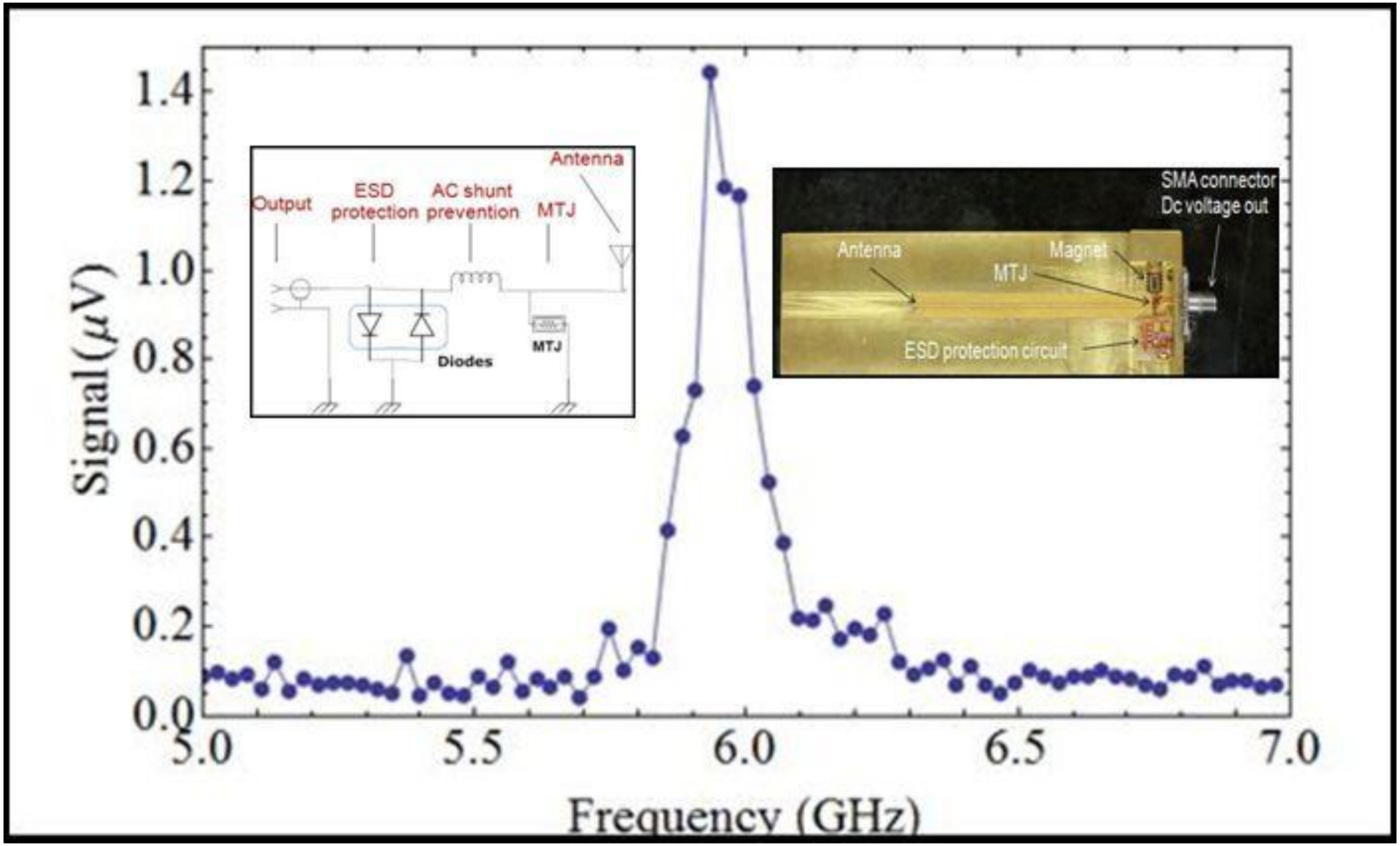


Metal tunnel junction detector



Antenna bonding to detector

ESD protection circuit added to the antenna



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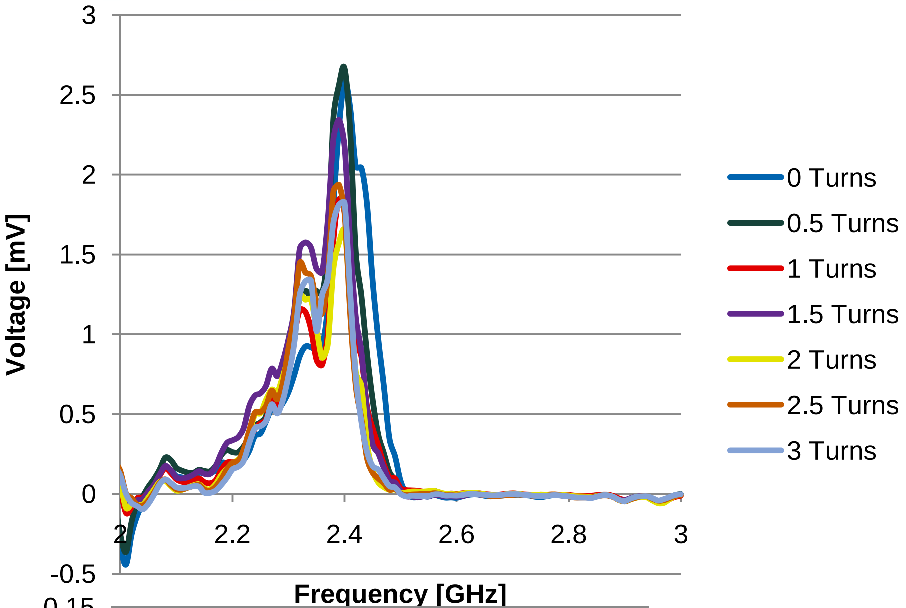
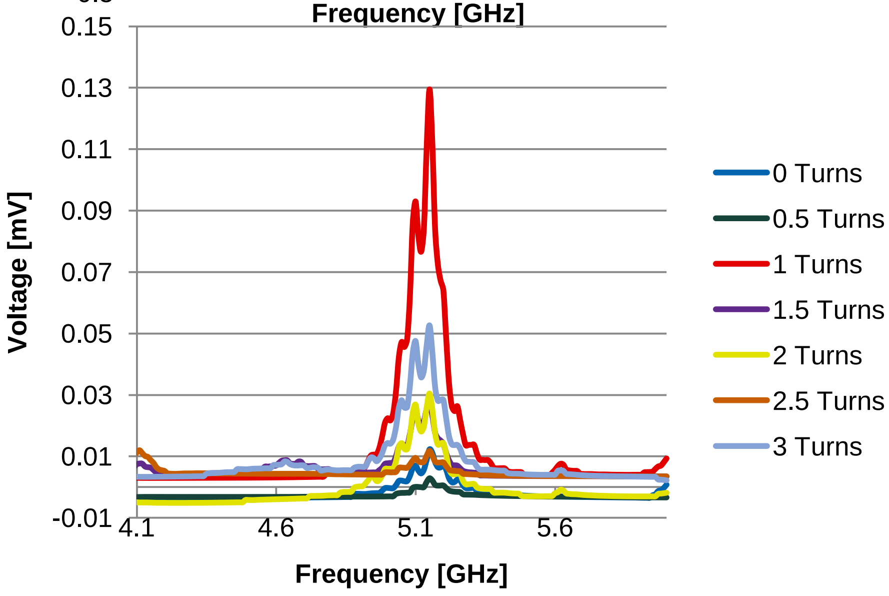
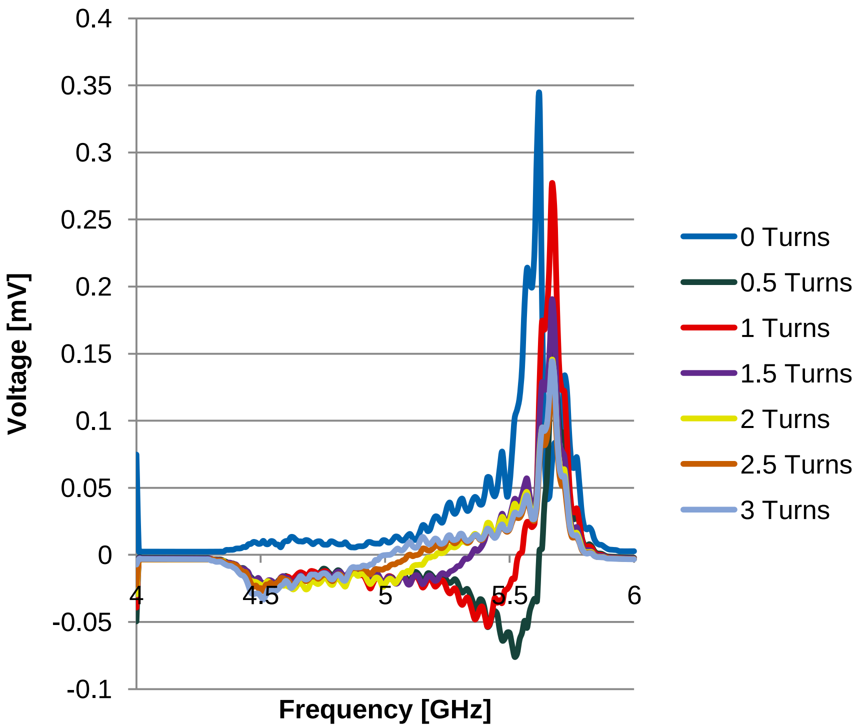
Detector Characterization: 1B, 2A and 4A







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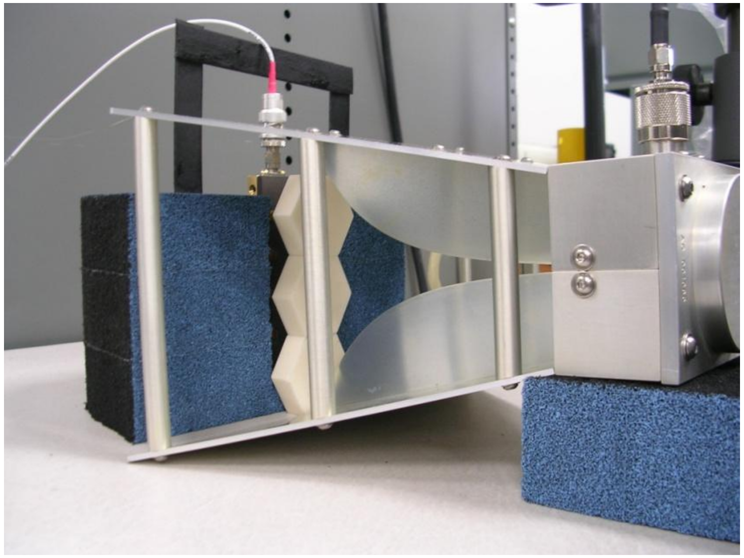
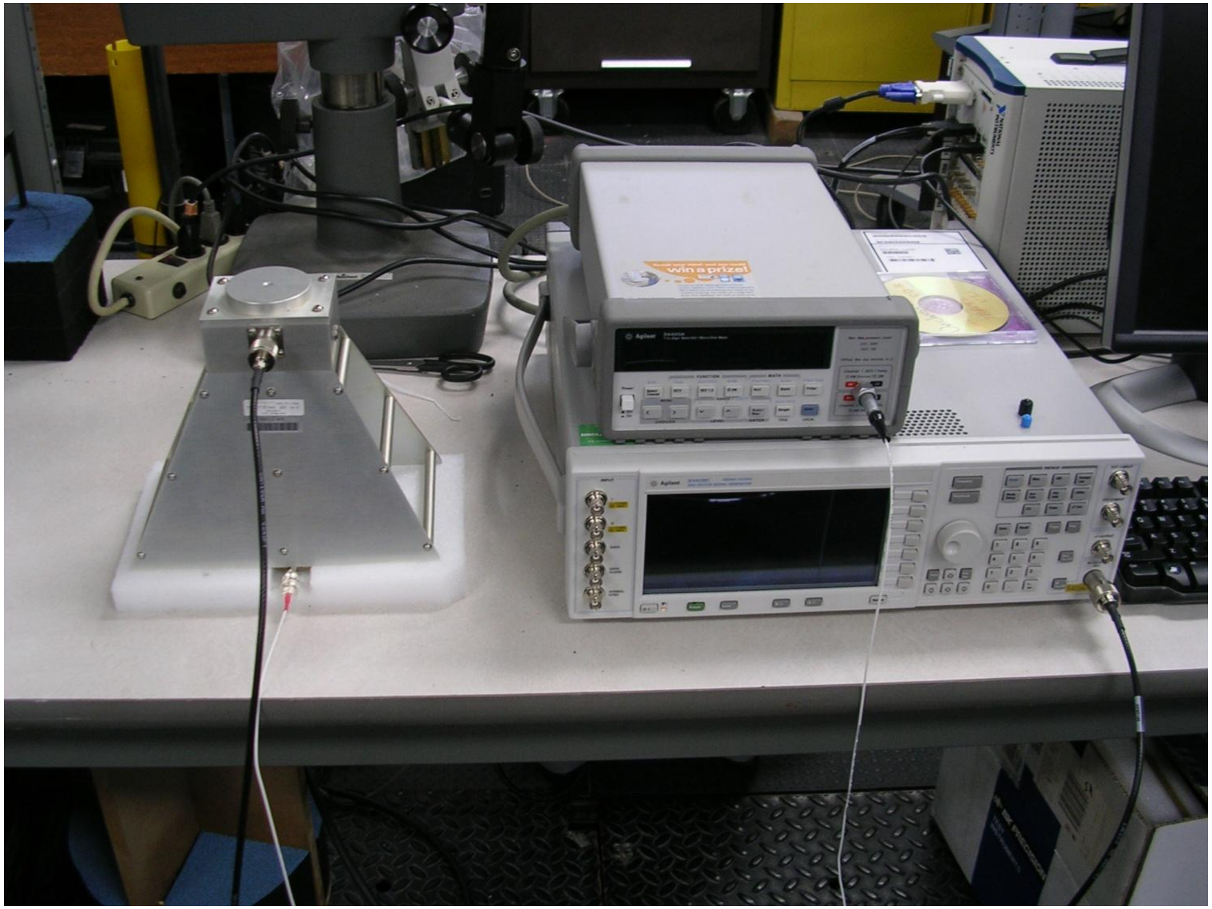
Detector Distance Testing

- The detector was moved away from the antenna and tested at 0in, 6in, 12in, and 24in distances
- Tests performed both in the anechoic chamber and on the bench.
- Armor tiles placed in front of the detector to test material (ceramic, SiC) transmittance



Test Equipment



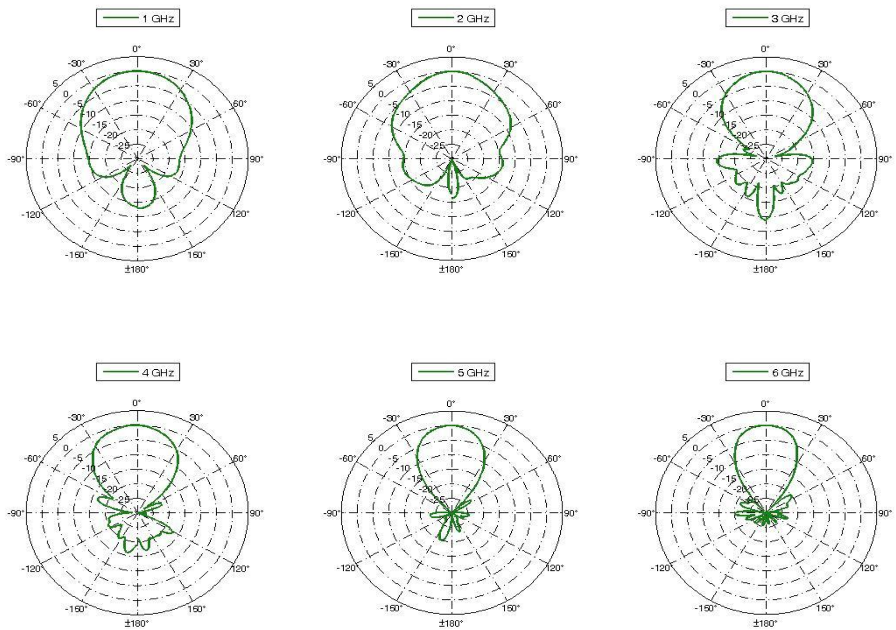
Horn antenna

Nano voltmeter

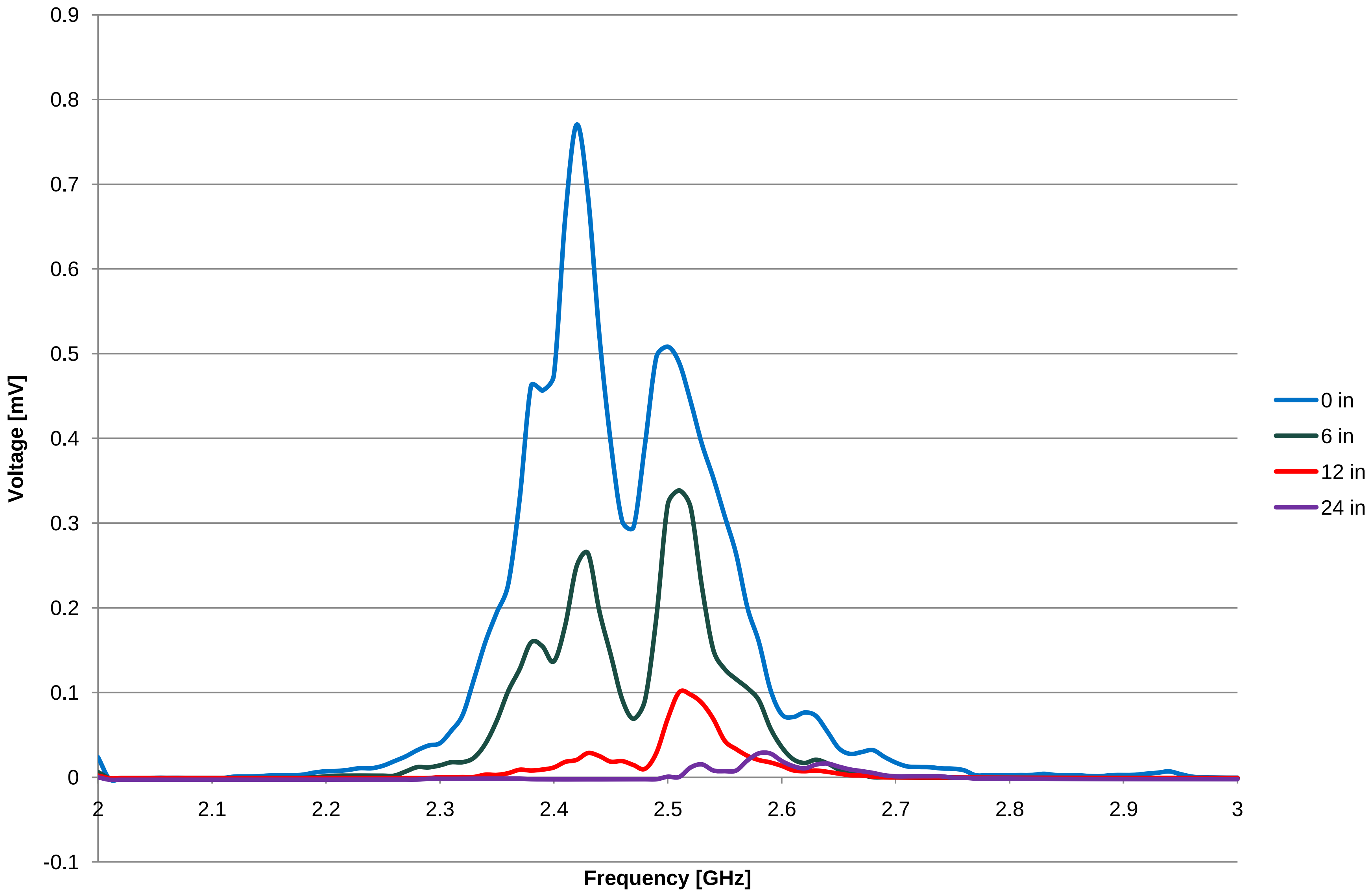
RF signal generator

Horn Radiation Patterns

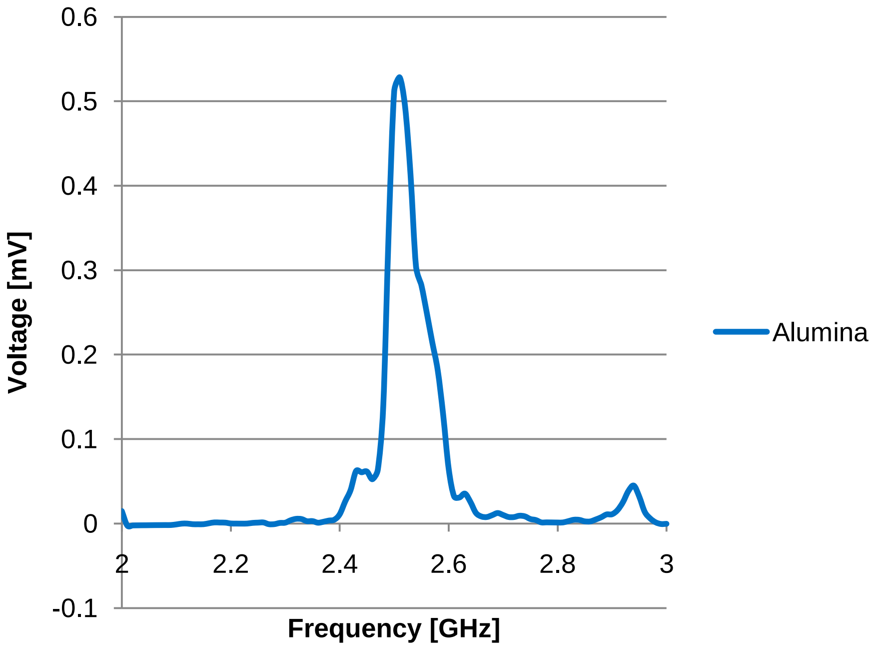
- Horn radiation patterns taken using UC-I and TARDEC horn antennas
- Graphs represent accurate patterns, but not magnitudes due to normalization

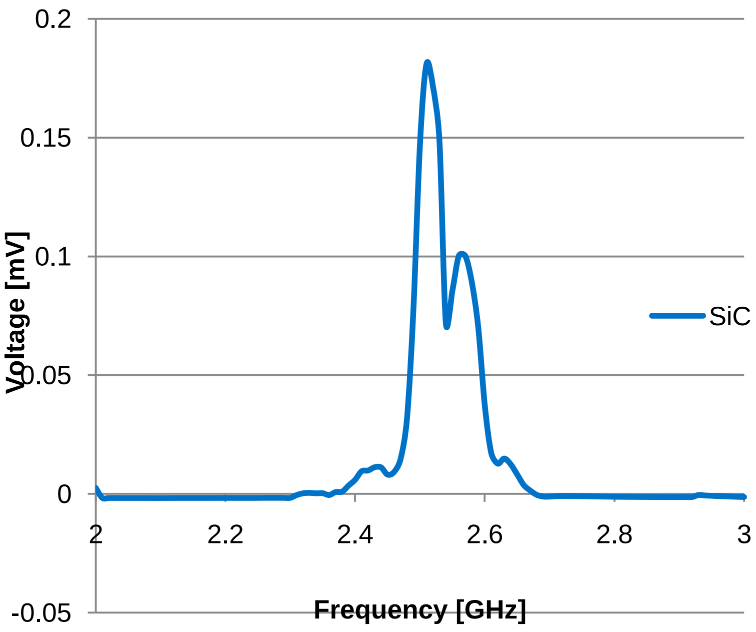


Detector Distance Testing: Bench



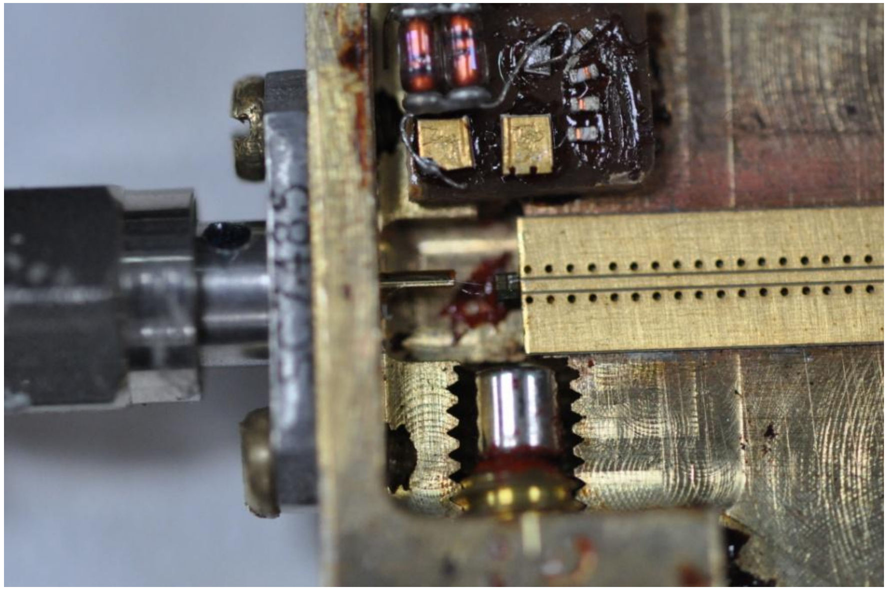
Detector Distance Testing: Alumina and SiC Tile





Duroid cover over device

- Effects of the Duroid Cover tested
- Duroid amplified some frequencies, but attenuated others



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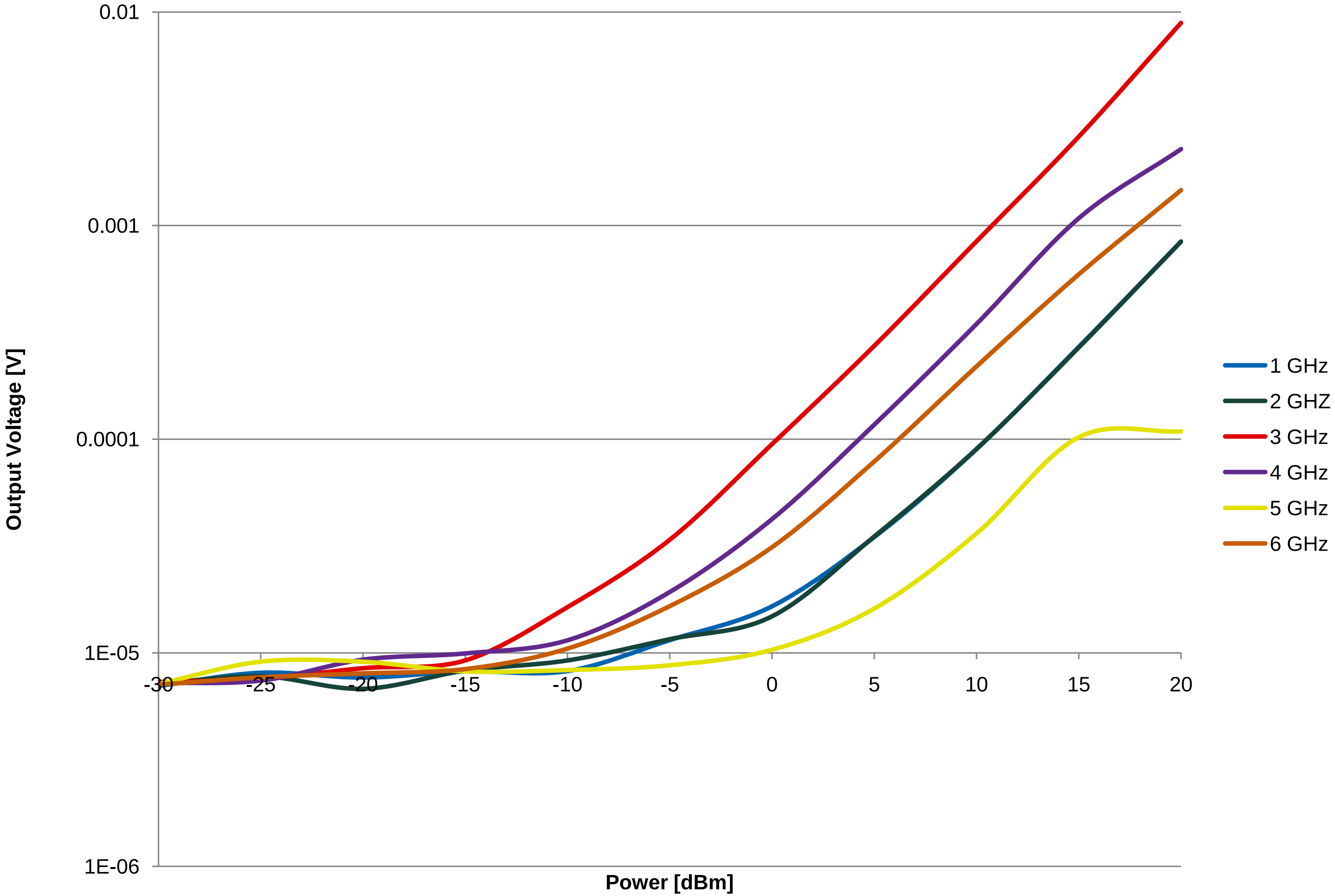
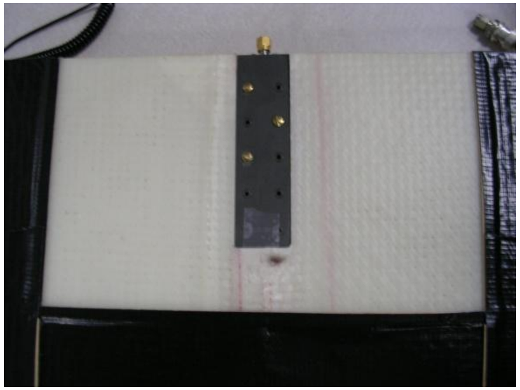
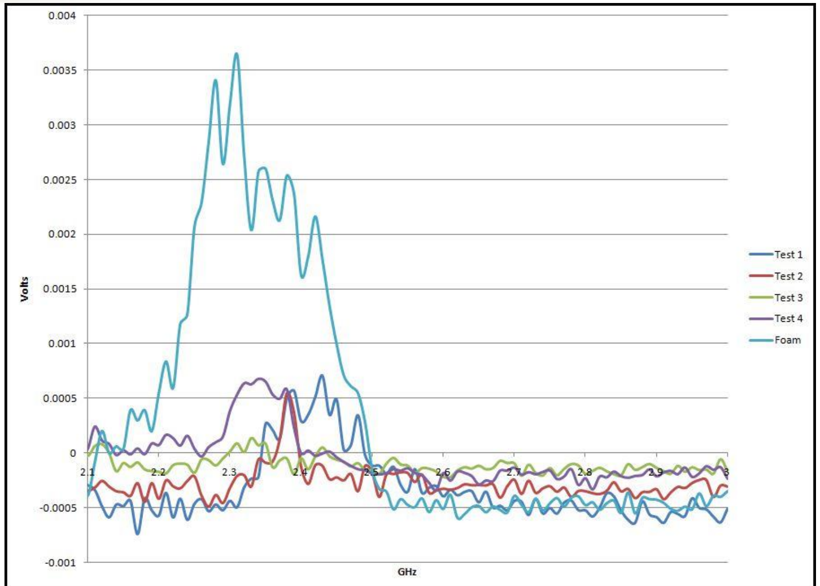
Duroid Cover



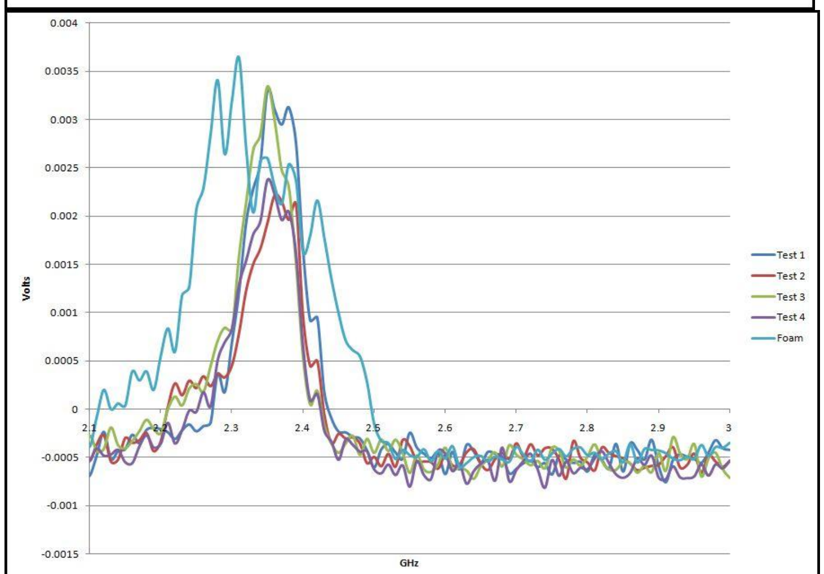
Performance of the antenna and detector embedded in armor



Front of surrogate armor



Small amount of attenuation by the armor coupon in some cases.



Back of armor

More stable signal behind the armor.

Transitions

• We think that spintronic microwave sensors/detectors are an important nano technology that in the future will become an essential and vital part of the anti-radar and communications defense systems for military ground vehicles and aircrafts and that this technology will substantially increase system survivability.

• The successful completion of this project advances our understanding of the physical processes in nano-scale magnetic structures at microwave frequencies. Besides military and space-oriented applications, spintronics technology can also be used in commercial electronic devices, in particular, for the development of wireless intra- and inter-chip communication systems in nano-electronic integrated circuits.

• This research can fall under the future umbrella of Army metamaterials research and multifunctional armor.